EVOS PROPOSAL SUMMARY PAGE

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Project Title: Surface nutrients over the Shelf and Basin in Summer – Bottom up Control of Ecosystem Diversity; submitted under the BAA

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Trustee Agency: NOAA

Abstract:

Our goal is to better understand the extraordinary variability of nutrients (spatial, interannual and decadal), and factors controlling nearshore communities and zooplankton and juvenile salmon distributions in the northern GOA. We propose monitoring nitrate over the shelf and basin. Underway samples will be collected as part of the NMFS-OCC/GLOBEC salmon survey in July/August of 2003 and 2004. This survey includes a transit across the central GOA and 10 cross-shelf oceanographic and juvenile salmon transects from Yakutat to Kodiak Island. This will be the broadest nutrient survey of the northern GOA. Nutrient maps will be used to support NPZ models and satellite-derived models of nitrate and new production, to examine mechanisms of nutrient supply such as mixing over banks and transport up submarine canyons, and to assist resource management of salmon and other commercially important species. Funding in 2003 ($37.5k) is crucial as this is GLOBEC's final intensive field season.

I. INTRODUCTION

The Gulf of Alaska represents one of the most productive marine ecosystems in the world, but is especially sensitive to meteorological and climate forcing. Record high sea-surface temperatures in 1997 and 1998 contributed to notable shifts in biological species and abundance (Mantua, 1997; Minobe, 1997; McFarlane & Beamish, 1999). Also, increasing temperatures and reduced salinities over the past several 9 decades resulted in a thinning of the mixed layer in the central Gulf of Alaska (GOA) and reduced entrainment of nutrients in the upper water column (Freeland et al, 1997). Recent warm events have suppressed upwelling off of Vancouver Island resulting in nutrient depletion and abnormally low chlorophyll concentrations occurring hundreds of kilometers offshore (Whitney et al., 1998, 1999).

It is uncertain if similar nutrient deficiency also occurs in downwelling regions along the Alaskan coast; to date, time series measurements of nutrients are too sparse to support such a claim. While it is generally assumed that surface waters are nutrient depleted in summer, satellite images show regions of high chlorophyll east of Prince William Sound (PWS, Stabeno et al., 2002). We hypothesize that while most of surface water in the northern GOA is depleted of nutrients in summer, there are regions of nutrient pumping (or nutrient hot-spots) that sustain new production – and that these hot spots are the basis for the high productivity and ecosystem diversity observed in the western GOA. Long-term monitoring of nutrient levels in the northern GOA is essential if we are to understand mechanisms which support summertime production, and understand variability of these mechanisms in relation to meteorological and climate forcing on interannual (e.g. El Nino/Southern Oscillation, ENSO), decadal (e.g. the Pacific Decadal Oscillation, PDO), and century (e.g. greenhouse warming) time scales.

In this proposal, we initiate a long-term monitoring program of surface nutrient concentrations across the northern GOA. These results will be combined with data from Fisheries-Oceanography Coordinated Investigations, GLOBEC, and the Steller Sea Lion Program, and with time-series measurements made from Vancouver Island to Ocean Station Papa (OSP). Results from this project will improve our understanding of mechanisms that supply nutrients to the shelf, our understanding of differences between the eastern and western GOA, and our understanding of bottom-up control of nearshore communities and plankton and fish distributions. Ultimately, we hope to use this project as a springboard for continued nutrient time-series measurements that will greatly benefit resource management in the northern GOA.

II. NEED FOR THE PROJECT

A. Statement of Problem

Climate forcing greatly impacts processes controlling the distribution of nutrients, and hence productivity in the Gulf of Alaska (GOA). For example, decreases in wind mixing, entrainment, and on-shelf transport of nutrients are predicted to be a consequence of long-term global warming (U.S. GLOBEC, 1996). Indeed, evidence suggests that the North Pacific may already be warming. Long-term records of SST at coastal stations in British Columbia reveal a 1-2ºC per century increase (Freeland et al., 1997; Whitney et al., 1999). Concomitant with increasing SST over the past several decades has been a thinning of the mixed layer and reduced winter entrainment of nutrients in surface waters at Ocean Station Papa (OSP) in the southern GOA

(Freeland et al., 1997). Along Line-P (Figure 1), the extent of seasonal nutrient depletion was more widespread in the 1990s relative to historic (1970s) observations (Whitney et al., 1998). Most stunning was the westward extent of nitrate depleted surface water in late summertime during the mid 1990s, especially in 1994 when surface waters were depleted westward to 140ºW (Figure 1, Whitney et al., 1998). It has been estimated that associated with lower nitrate concentrations along Line-P are chlorophyll concentrations about half of historic levels (Whitney et al., 1999).

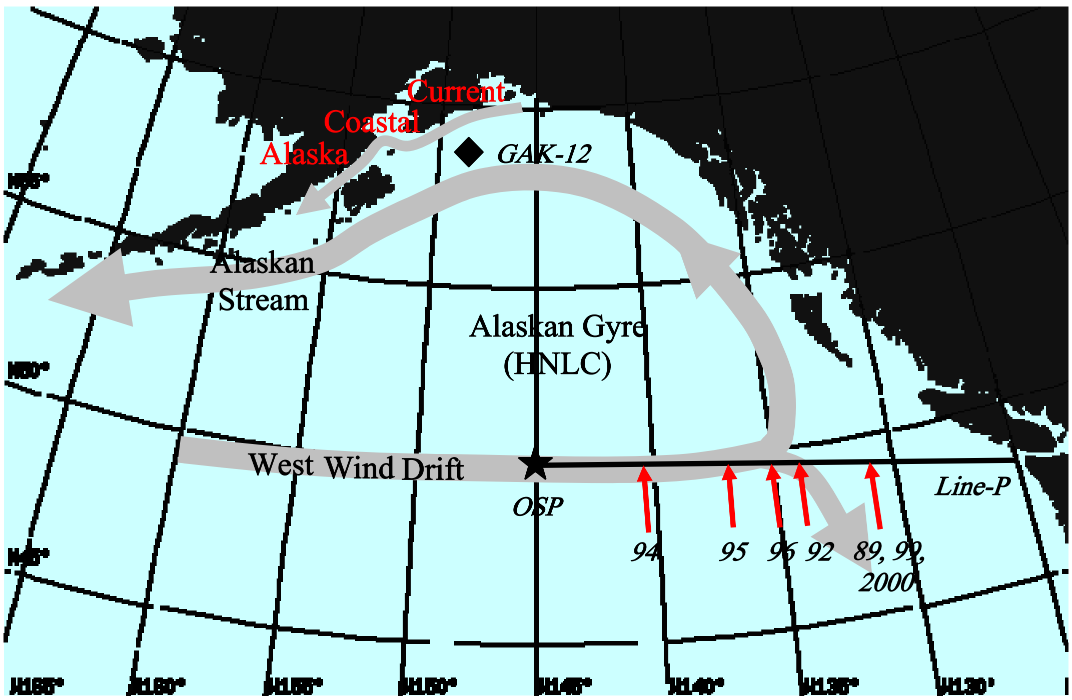

Figure 1. Map of the Gulf of Alaska showing general circulation (after Reeburgh & Kipphut, 1987), the location of Ocean Station Papa (OSP), Line-P, GAK-12, and the seaward extent of late summer nitrate depletion along Line-P (red arrows) for years 89, 92, 94, 95, 96 (after Whitney et al., 1998), 99, and 2000 (Whitney, pers comm.).

The 97-98 ENSO event had a similar impact on the nitrate field. Warmer waters increased buoyancy of the winter mixed layer suppressing winter entrainment and coastal upwelling. As a result, along Line-P, nutrient concentrations were about half as large as observed in the 1970s with nutrient depletion occurring 1 month earlier than in previous years (Whitney et al., 1999).

Physical forcing in the Northern GOA greatly differs from forcing along Line-P. For example, shifts in the bifurcation of the West Wind Drift can lead to variability in the GOA and perhaps along Line-P (Chelton & Davis, 1982). Also, the conditions off Vancouver Island often favor upwelling (30-40% of summer winds off Vancouver Island are upwelling favorable, N. Bond, pers. comm.), whereas the opposite is true for the northern GOA. Nevertheless, the variability of nitrate was similar for the northern and southern GOA during the 1998 ENSO. GLOBEC-LTOP monitoring data show dramatic changes in the nutrient fields from 1998 to 1999. In 1998, nitrate concentrations shoreward of GAK 12 were lower by about 1/3 relative to 1999, and regions of surface nitrate depletion appeared one month earlier (http://murphydome.ims.uaf.edu:8000/globec/results/). Spatial variability of nitrate depletion could not be determined as the LTOP survey was not broad enough to examine the seaward extent of nitrate depletion.

The oceanography of the northern GOA as recently been reviewed by the principal investigators of this proposal (Stabeno et al., 2002). The principle circulation feature of the GOA is the Alaska Current/Alaskan Stream (e.g., Favorite et al., 1976). The flow generally parallels the continental slope, moving northward then turning westward where the flow becomes faster and more focused (Figure 1). Seasonal variations in the volume transport of the current are relatively small (~13%) compared to estimates of interannual variability (Reed and Schumacher, 1986). The stream acts as a barrier between the central GOA and waters over the shelf.

The central GOA is a region of weak upwelling with nutrients supplied to the surface in abundance through winter entrainment across a deep and weakly stratified mixed layer. It has been characterized as a High Nutrient - Low Chlorophyll (HNLC) region as iron limitation is believed to curtail primary production in summer (Martin et al., 1989), resulting in high nutrients and low chlorophyll concentrations despite warmer temperatures and stronger stratification.

Conditions shoreward of the Alaska Current/Alaskan Stream are much more variable than the central GOA. Strong easterly winds in fall and winter generate downwelling conditions that are generally unfavorable for primary production. In the spring and summer, increased irradiance and a reduction (or even a reversal) in downwelling conditions (weaker alongshore winds) spawn substantial phytoplankton blooms – blooms that deplete nutrients in surface waters.

The most notable oceanographic feature of the shelf is the Alaska Coastal Current (ACC). This current is thought to be wind driven with a strong baroclinic signature. Maximum transport is in winter when downwelling forcing is greatest, and the greatest baroclinic signal is in autumn coinciding with maximum freshwater discharge. The ACC provides critical habitat for numerous fish species; it is a nurturing area for larvae of demersal shelf species, and a migration pathway for juvenile and adult salmonids.

The ultimate control of a complicated ecosystem, such as the one found in the northern GOA, is the physical control that govern the availability of food to the lowest trophic levels. If conditions of physical mixing, nutrient and light availability change primary production or the timing and composition of the primary producers, the entire food web structure can be affected (Napp et al., 1996). For example, a climate-induced loss of nutrients and primary production along the west coast was thought to impact fish survival (Welch et al., 2000). In the northern GOA, strong evidence suggests significant changes in fish abundance and composition are associated with environmental shifts (Merrick, 1995; Shima, 1996; Mueter, 1999).

In 1977, a regime shift in the Pacific Decadal Oscillation (PDO) to a warm phase was coincident with a ~50% decline in fish biomass (Piatt & Anderson, 1996) – a decline in prey for the top predators. For example, during this time the primary prey of the Steller Sea Lion shifted from mostly rockfish and capelin – which declined greatly in population, to Walleye pollock (Pitcher, 1981, Shima et al., 2000). This change in diet and prey abundance appears to have increased the nutritional stress of adult females resulting in greater reproductive failures (Pitcher et al., 1998). Also, due to the limited foraging range of young Steller sea lions, changes in prey abundance and distributions may have limited the success of these juveniles (Merrick & Loughlin, 1997; Shima et al., 1996). A study of Steller population dynamics indicated that increased mortality of juveniles due to the 1977 PDO shift could result in a dramatic decline in Steller population similar to the observed trend (Shima, 1996).

It does appear that variability of biological populations is coincident with environmental oscillations. Thus, a careful monitoring of meteorological forcing, climate forcing, and nutrient distributions may help to explain observed biological variability. Time series measurements along Line-P have proven invaluable for understanding the impact of warmer SST and climate events on regional nutrient fields and primary productivity, without which recent conditions could not be put in context. However, these results pertain to the coastal upwelling regime off Vancouver, and may not be representative of conditions in the downwelling regime of the northern GOA. Although several years of GLOBEC monitoring data are now available along the south coast of Alaska, large scale mapping of nutrient fields has not occurred. We have begun underway sampling of nitrate and fluorescence during GLOBEC and Steller Sea Lion mooring cruises in May and September (see Section IIIC), however the spatial coverage is severely limited.

Nutrient data across the northern GOA are sparse and insufficient for diagnosing spatial and temporal variability, or for understanding mechanisms of nutrient supply to surface waters at the coast and over the shelf. This would best be done in summer, when nutrient depletion over much of the shelf provides the perfect backdrop for identifying local regions of nutrient pumping, or nutrient hot-spots. But it is evident from a recent map of summertime nitrate concentrations in the GOA (Figure 2) that not much can be deduced from this paucity of data.

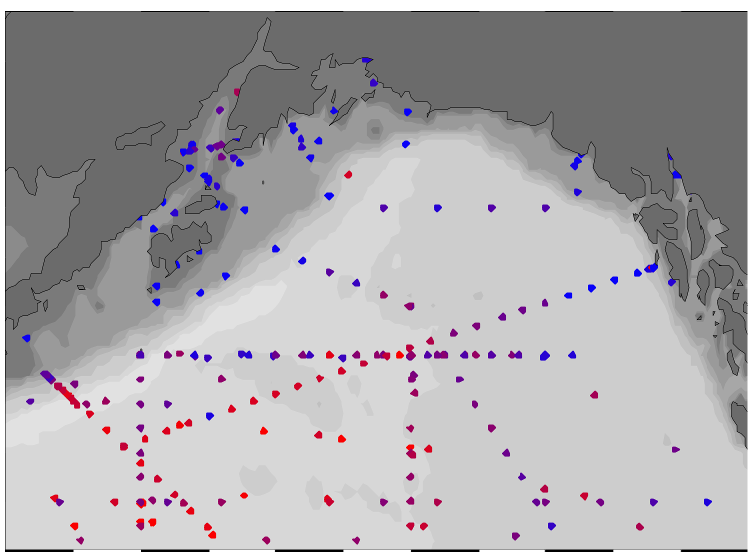

Figure 2. Surface map of NODC and WOCE nitrate data in June-September since 1971.

However, satellite images of ocean color suggest that there are active mechanisms of nutrient supply in the western GOA in summer – mechanisms that may help explain why this downwelling shelf is so productive (Stabeno et al., 2002). Surface waters east of PWS have relatively low chlorophyll concentrations, while concentrations west of PWS can be very high. The most probable mechanisms suggested through our GLOBEC and Steller Sea Lion research are on-shelf transport of deep nutrient-rich water up submerged sea valleys, and tidal/storm mixing over shallow banks. (Ekman transport of nutrient rich surface water from the central gyre to the shelf is less important in summ0er when downwelling winds are weak, and nutrients advection from eddies and baroclinic instabilities could not account for chlorophyll distributions observed in the western GOA.)

As the supply of nutrients appears critical for both nearshore and shelf ecosystems (see Section IIC), we propose to obtain broad high-resolution maps of nitrate using an automated underway nitrate monitor installed on the F/V *Great Pacific* during annual National Marine Fisheries Service (NMFS) Ocean Carrying Capacity (OCC) / GLOBEC salmon surveys in 2003 and 2004. These are the last two years of the OCC / GLOBEC survey, and the final intensive field year for GLOBEC process studies. Thus, to maximize the partnership between GEM and GLOBEC, funding in 2003 is especially important.

Underway nitrate concentrations will be verified from discrete samples collected 4-6 times per day from the underway stream, and from surface samples collected during CTD casts. Discrete samples will be frozen and analyzed at PMEL for nitrate, phosphate, silicic acid, nitrite and ammonia. The underway system on the ship includes a thermosalinigraph (temperature and salinity), an underway fluorometer, and an ADCP which operates continuously and is corrected for tides to reveal the flow field. The cruise track includes a dead-head from Dutch Harbor to Yakutat which crosses the central GOA, then 8 cross shelf transects from Ocean Cape to Cape Kaguyak, and 2 transects across Shelikof Strait (Figure 3).

As outlined below (Section IIIA&B), the objectives of this project are to map surface nutrients across the northern and central GOA, identify mechanisms that supply nutrients to surface waters in summer, parameterize the relationship of nutrient distributions with physics, chlorophyll, zooplankton and fish, provide a mesoscale context for studies in the western GOA (FOCI, GLOBEC and the Steller Sea Lion Program), and for research proposed in the eastern GOA (Coastal Ocean Processes). This approach is essential for understanding the supply of nutrients to nearshore communities, and the impact of climate events on nutrient supply to the coastal GOA. These results will also be used to improve multi-variate algorithms for predicting nitrate from various biophysical parameters – predictions that may indicate large-scale variability in nitrate prior to, during, and subsequent to the strong ENSO event and PDO regime shift at the end of the last century. Those climate events may portend future biophysical conditions concomitant with global climate change.

The Principal Investigators on this proposal have a long record of accomplishment in the GOA, and are currently involved in numerous field programs in the northern GOA (see Section IIIE). C. Mordy has deployed underway monitors on the most recent GLOBEC cruises, and will be responsible for operation of the underway system. P. Stabeno is a PI on the OCC/GLOBEC salmon survey and will be responsible for synthesizing data from these two projects. Data from the OCC/GLOBEC salmon survey include underway measurements and numerous trawls along each of the transects. Each trawl site consists of a CTD, surface tucker net hauls to give zooplankton distributions, analysis of juvenile salmonid stomach contents to compare with zooplankton distributions, and analysis of otoliths for hatchery thermal marks and Genetic Stock Identification techniques to determine home streams of hatchery and wild salmon stocks and their distribution in relation to oceanographic regimes. The OCC/GLOBEC salmon survey includes a retrospective analysis of catch per unit effort versus oceanographic and prey factors to better understand what affects the distribution of pink, chum, coho, and sockeye salmon in the northern GOA. Without knowledge of nutrient concentrations, there can be little hope of fully understanding the distributions of plankton, or the distribution of animals dependent on plankton.

Most of the funding of this work will be leveraged from FOCI, GLOBEC, and Steller Sea Lion funds including ship time, the underway nitrate monitor, installation of the underway system, laboratory analysis of frozen discrete samples, computer time, and salary for P. Stabeno. Our request is only for travel, salary for C. Mordy and a technician (D. Wisegarver), and various supplies.

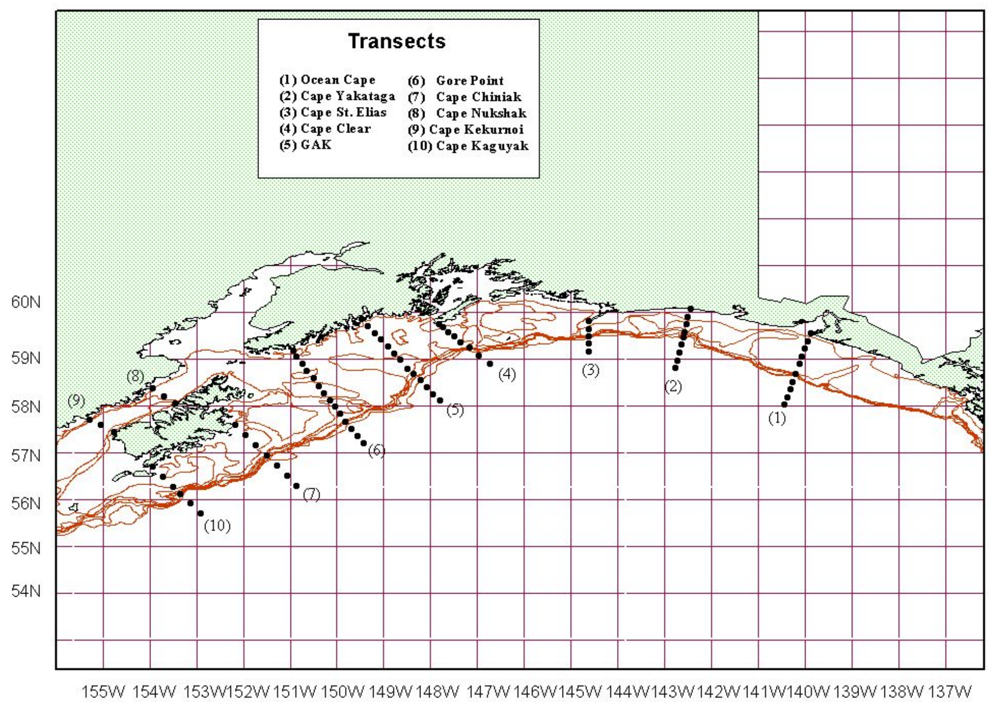

Figure 3. Transects and station locations sampled by the NMFS OCC program in the Gulf of Alaska July 11 – August 8, 2002. Not shown is the dead-head from Dutch Harbor to Yakutat, or the station-to-station transits.

B. Rationale/Link to Restoration

In establishing the GEM Program, the Trustee Council explicitly recognized that complete recovery from the oil spill may not occur for decades and that full restoration of injured resources will most likely be achieved through long-term observation and, as needed, restoration actions. The Council further recognized that conservation and improved management of injured resources and services will require substantial ongoing investment to improve understanding of the marine and coastal ecosystems that support the resources, as well as the people, of the spill region. In addition, prudent use of the natural resources of the spill area without compromising their health and recovery requires increased knowledge of critical ecological information about the northern Gulf of Alaska. This knowledge can only be provided through a long-term monitoring and research program that will span decades, if not centuries.

This proposal would initiate long-term monitoring of the nutritional status of the northern GOA – and provide the basis for recognizing full restoration of the ecosystem.

C. Link to GEM Program Document

Given the paucity of nutrient data in the northern GOA, it is not surprising that the GEM program document makes repeated references to the need for better monitoring of nutrients. These references are found throughout discussions of the Intertidal/Subtidal, ACC, and Offshore habitat areas. The following paragraphs are taken directly from the program document and very clearly demonstrate the relevance of the proposed work to these GEM components.

Intertidal and Subtidal:

> Nutrient supply to fixed plants is not well characterized, but presumably is controlled by oceanographic processes and seasonal cycles of water turnover on the inner shelf as well as some contributions from stream runoff. This process of nutrient supply is essentially the same as for nearshore phytoplankton. Ultimately… the runup of deepwater from the central GOA onto the shelf and some poorly characterized processes for cross-shelf transport of the nutrients are critical to growth of both fixed and floating nearshore algae. The nearshore waters can be depleted of nutrients during the growing season if the warm surface layers where primary productivity is drawing down nutrients is not mixed with deeper waters by wind and tidal action. … It is suspected that bottom-up forcing through variability of primary production is an important influence on intertidal invertebrate communities on the scale of decades, but there are no long-term data sets to examine this supposition.

Alaska Coastal Current:

> Annual variability of nutrient supply likely has a great influence on long-term variability in primary production. For example, this influence would be consistent with the relationship between the Bakun upwelling index and pink salmon marine survival rates up to 1990 and the differences observed between the volumes of settled plankton in the 1980s and in the 1990s (Brown, unpublished).
>
> What is the variability in the supply of deepwater nutrients to the photic zone of the ACC and their concentrations in that zone on time and space scales appropriate to understanding annual primary production?
> *Specific Information Needs:* Measurements of, or proportional to, macronutrients and micronutrients at appropriate spatial scales.

Offshore:

How are the supplies of inorganic nitrogen, phosphorus, silicon, and other nutrients essential for plant growth in the euphotic zone annually influenced by climate-driven physical mechanisms in the GOA?
Specific Information Needs: Measurements of inorganic nitrogen, phosphorus, silicon, and other nutrients on time and space scales appropriate to understanding annual variability.

What is the role of the Pacific High Pressure System in determining the timing and duration of the movement of dense slope water onto and across the shelf to renew nutrients in the coastal bottom waters?
Specific Information Needs: Synoptic information on sea level pressure and horizontal and vertical structure of density and nutrients on the outer continental shelf and Alaska Gyre in relation to the ACC on appropriate time and space scales.

Is freshwater runoff a source of iron and silicon that is important to marine productivity in the offshore and adjacent marine waters?
Specific Information Needs: Levels of biologically available silicon and iron from offshore water in relation to the ACC on appropriate time and space scales.

We hope to extend this project into a long-term monitoring program of the nutritional status of the northern GOA, and through a broad interdisciplinary partnership with other programs and modeling and resource management teams, we foresee a monitoring network which closely matches the GEM vision.

> The end point for monitoring is a geographically distributed network gathering data on the state of the marine ecosystem in the GEM region, using spatially structured survey methods. This implies a broad spatial scale for monitoring, as a combination of GEM with that of other entities. These data are transformed into information for user groups by using synthesis, research, modeling, data management, and information transfer.

III. PROJECT DESIGN

A. Objectives

The objectives of the proposed research are to examine nutrient supply to nearshore surface waters, explore bottom-up control of plankton and fish distributions along the shelf and in the central GOA, and to parameterize chemical, biological and physical processes influencing these distributions. The specific objectives of this research are to

Objective 1 Map surface nutrients across the northern and central GOA,

Objective 2 Identify mechanisms supplying nutrients to surface waters in summer,

Objective 3 Parameterize the relationship of nutrient distributions with physics, chlorophyll, zooplankton and fish, Objective 4 Provide a mesoscale context for moorings and process studies in the western GOA (FOCE, GLOBEC and the Steller Sea Lion Program), and for research proposed in the eastern GOA (Coastal Ocean Processes), and

Objective 5 Initiate a long-term monitoring program of the nutritional status of the northern and central GOA to better understand the impact of interannual and decadal variability, and to provide nutritional forecasts to resource management teams.

B. Procedural Methods

Objective 1. Map surface nutrients across the shelf of the northern GOA.

Hypothesis: In summer, surface waters over the shelf are 1) depleted in nutrients east of PWS, and 2) relatively abundant in nutrients west of PWS. Method: Install an underway nitrate monitor on the NOAA chartered F/V *Great Pacific*. The details for mounting the instrument have already been discussed with the Owner, the Captain, and the Chief Engineer of the F/V *Great Pacific*, as well as Dr. E.D. Cokelet who is the GLOBEC PI responsible for the underway system. All are in agreement that the instrument would be a welcome addition to the science already on-board (see supplemental letter of collaboration from E.D. Cokelet).

The W.S. Ocean AutoLAB is an automatic shipboard nitrate measurement package that has been deployed by Mordy during FOCI and GLOBEC cruises in the northern GOA in 2001 and 2002. A technician will ride the ship during the first leg to ensure proper operation of the instrument, and adequate calibration sampling by the science party. The nitrate monitor uses standard wet chemistry techniques for diazotizing and coupling reduced nitrate and nitrite, for and measuring the absorbance of the resulting red azo dye. This method is directly comparable to the autoanalyzer that will be used by Mordy to evaluate monitor performance. The automated underway system will sample every 3 minutes with standards analyzed 3-4 times per hour. Standards will be stabilized by pasteurization, with concentrations verified before and after each cruise. This technique for stabilizing standards has been used for moored nitrate analyzers and nitrate concentrations are stable for over 6 months. The AutoLAB makes corrections for background absorbance and sample turbidity.

Discrete calibration samples will be collected from the ship's underway system and from the CTD-bottle rosette. They will be frozen at –20°C, returned to PMEL, and analyzed according to WOCE-JGOFS protocols (Gordon et al., 1993). Mordy has extensive experience conducting nutrient analysis under these protocols, which include blank analysis (refractive index, distilled water reagent blank, low nutrient seawater blank) and high-precision standard preparation using gravimetrically calibrated - temperature corrected - pipettes (Eppendorf Maxipettors) and glassware. Standards have been cross-calibrated with standards with other nutrient laboratories (e.g. Lou Gordon at Oregon State University).

Performance Measure:
Quality of data – 3% accuracy, 3% precision relative to high surface concentrations in the central gyre.
Quantity of data – spatial coverage including the central GOA from Dutch Harbor to Yakutat, and shelf waters from Yakutat to Kodiak and Shelikof Strait.

Objective 2. Identify mechanisms that supply nutrients to surface waters in summer.
Hypothesis: In summer, nutrients in surface waters are enriched from deep mixing over shallow banks, from flow up submarine canyons, from estuarine flow up Shelikof Strait, and from intrusions of nutrient-rich water from the central GOA.
Method: Identifying mechanisms of nutrient supply are major goals of the GEM, FOCI, GLOBEC and Steller Sea Lion programs. However, the FOCI, GLOBEC and Steller Sea Lion programs lack broad nutrient surveys of the GOA. The proposed survey will cross shallow banks and canyons off Kodiak, make two hydrographic transects across Shelikof Strait, and make eight transects to the shelf break where intrusions of water from the central Alaskan Gyre are common. To fully address this objective, data from the proposed survey will be combined with FOCI, GLOBEC, and Steller Sea Lion data including results from moorings, drifters, hydrographic cruises, satellites and meteorological stations. This hypothesis might not be fully realized until completion of our GLOBEC program in 2005.

Objective 3. Parameterize the relationship of nutrients with physics, chlorophyll, zooplankton and fish.
Hypothesis: Nitrate and new production can be predicted from space using ocean color and SST.
Method: Use stepwise multiple regression techniques described in Section C below to examine spatial and temporal variability in the relationships between nitrate, temperature, salinity and chlorophyll; and compare algorithms from various habitats to algorithms used for satellite estimates in the North Pacific. We will also provide surface nitrate maps to ground truth satellite estimates of nitrate.
Performance Measure: Predict nitrate to $\pm 2\ \mu M$.

Hypothesis: There is a strong correlation between nutrients and the distribution of primary and secondary production.
Method: This hypothesis assumes strong coupling between primary and secondary production. While this condition may be typical of spring blooms (mostly nitrate based production), it is not necessarily the case in summer when regenerated production dominates. However, off Kodiak Island, there appear to be sources of nitrate, or nutrient "hot spots" in mid-summer. We will use stepwise multiple regression analysis of physical, chemical and biological parameters to test for tight coupling between physical forcing, nutrient supply and the distributions of primary and secondary producers.

Objective 4. Provide a mesoscale context for moorings and process studies in the western GOA (FOCI, GLOBEC and the Steller Sea Lion Program), and for research proposed in the eastern GOA (Coastal Ocean Processes).

See Section IIIE.

Objective 5. To initiate a long-term monitoring program of the nutritional status of the northern and central GOA, to better understand the impact of interannual and decadal variability, and to provide nutritional forecasts to resource management teams.

Hypothesis: Variability in SST alters stratification and entrainment of nutrients in the central GOA thereby reducing nutrient supply to the shelf via Ekman transport and eddies. Decreased nutrient availability leads to lower productivity and changes in plankton bloom dynamics that adversely affect fish recruitment.

Method: This hypothesis relates to observations in the southern GOA that indicate a decline in nutrients. Although GEM is not focusing on the offshore habitat at this time, a side benefit of this project is that such secondary questions will begin to be addressed. We will combine surface nutrient maps from GEM with those generated by F. Whitney along Line-P to gain an overall picture of nutrient depletion over the gulf.

Hypothesis: Modelers and resource managers can use knowledge of nutrient variability in habitat critical to the survival of juvenile fish to forecast annual fish stocks and recruitment.

Method: This hypothesis assumes that nutrient availability in a key habitat ultimately determines the survival of juvenile fish; that there is strong coupling between nutrients, primary, secondary and tertiary production, and that fish stocks and recruitment are largely a function of juvenile success. Addressing this very ambitious hypothesis is a long-term goal and cannot be fully realized under this proposal, but requires multi-year monitoring of key habitats. Fishery biologists participating on the OCC/GLOBEC salmon survey have identified such habitats (i.e. the ACC), and these areas are a significant component of the OCC/GLOBEC survey. Objective 3 addresses coupling between nutrients and secondary production, and NMFS/GLOBEC biologists are testing for tight coupling between secondary producers and juvenile fish. Climate events such as ENSO are known to dramatically alter nutrient fields and severely impact some species. Through long-term studies and future partnerships, we hope to parameterize the nutrient and biological response to such events.

C. Statistical Methods

The relationship of nutrients with temperature and/or salinity has been noted for many regions of the world's oceans (Smith, 1984; Maeda et al., 1985; Kamykowski & Zentara, 1986). A strong correspondence in upwelling zones (equatorial & coastal) has fostered efforts to estimate nutrients from temperature and/or salinity (Dugdale et al., 1989; Sathyendranath et al., 1991; Garside & Garside, 1995; Dugdale et al., 1997). For example, Garside & Garside (1995) used a multi-variate approach to predict nitrate in the North Atlantic and Pacific with standard errors of

0.5-1.0 μM. The strength of this relationship is a consequence high production that depletes nitrate during seasonal warming.

In the first use of compound remote sensing, Goes et al. (2000) used satellite measurements of temperature and chlorophyll to make basin scale estimates of nitrate and new production in the North Pacific. This advance was particularly important in regions of exceptional production and moderate seasonal warming – regions where the temperature-nitrate relationship was very weak. While the northern GOA appears to fall into this category, there is insufficient data to explore surface temperature-nitrate relationships on broad spatial scales (eastern GOA verses western GOA).

Stepwise multiple linear regression analysis (using StatView software) will be completed on underway nitrate, temperature, salinity and fluorescence in an effort to improve algorithms for estimating nitrate from compound remote sensing. Using underway data from May 2001, we were able to predict nitrate to +/-2uM (Figure 4). The temperature range of the data in spring was relatively small; thus, despite several fronts of nitrate and temperature, the temperature-nitrate relationship was not significant. Instead, fluorescence was the most significant independent variable, which reinforces the value of compound remote sensing. Data from this program will be provided in support of remote sensing efforts.

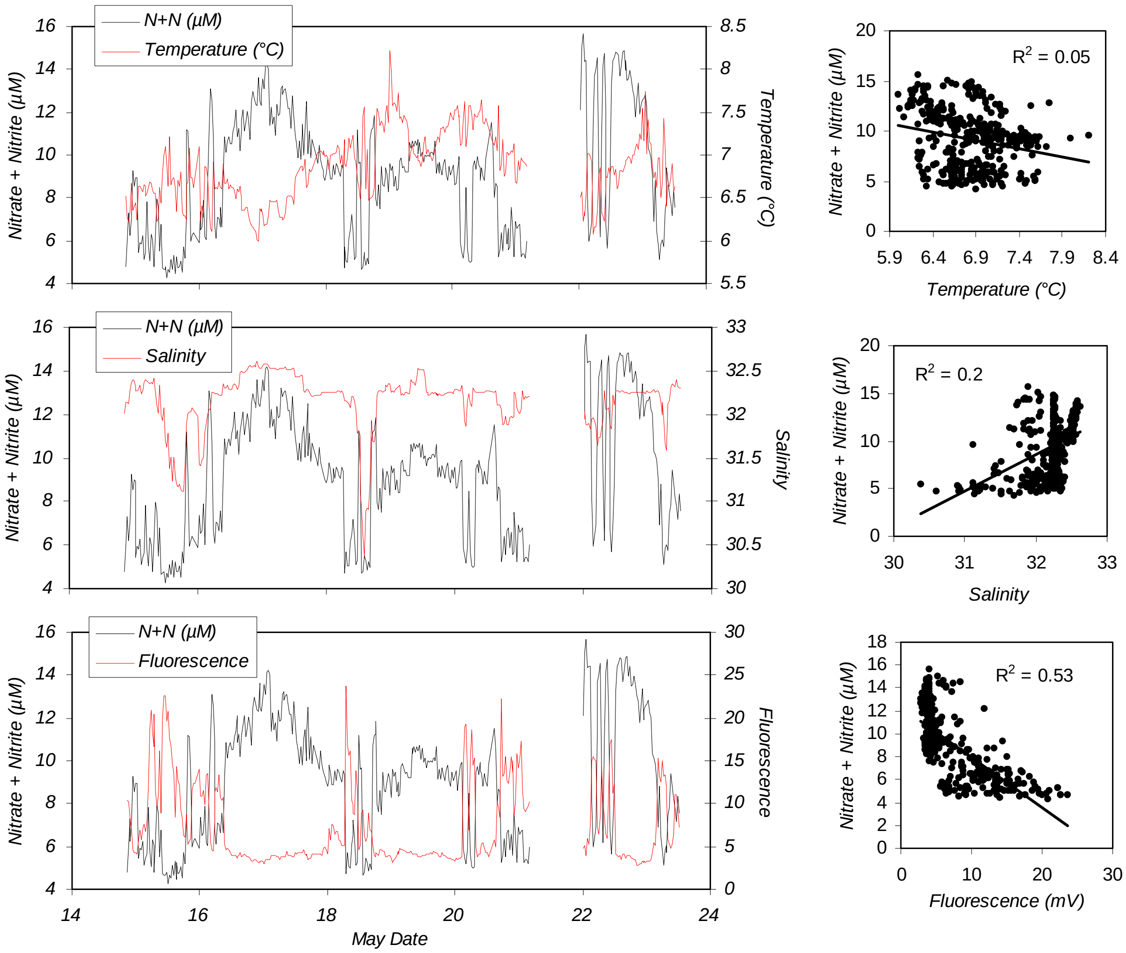

Figure 4. Underway measurements of nitrate, temperature, salinity, and fluorescence off Kodiak Island during the GLOBEC mooring cruise in May 2002.

D. Description of Study Area

The study area extends from Dutch Harbor to Yakutat. There will be a transit from Dutch Harbor to Yakutat, 8 transects from the coast to the shelf break, and 2 transects across Shelikof Strait (Figure 3). Those transects, from east to west, are at Ocean Cape, Icy Bay, Cape St. Elias, Cape Hinchinbrook, Cape Puget, Gore Point, Cape Chiniak, and Cape Kaguyak; and across Shelikif Strait are transects at Cape Nukshak and Cape Kekurnoi. Underway data will also be collected on transits between transects.

E. Coordination and Collaboration with Other Efforts

P. Stabeno directs NOAA's FOCI program, and P. Stabeno and C. Mordy are collaborating PIs on a second GLOBEC project, and two Steller Sea Lion Projects. In all, the PIs annually deploy

25-50 moorings (meteorological, biophsical, nitrate and iron) and numerous drogued drifters, and conduct 2 hydrographic cruises in the northern GOA. They also collaborate with GLOBEC modelers running high-resolution ocean circulation models, and NPZ models of the GLOBEC region. The combination of GEM nitrate maps with FOCI/GLOBEC/Steller Sea Lion mooring data, drifter, hydrographic and modeling data will help resolve mechanisms of nutrient supply to nearshore ecosystems in summer.

Through these other programs, PMEL is studying the possibility of purchasing a new optical nitrate sensor (http://www.satlantic.com/products/marine-instrumentation/nitrate/mbari-isus/). If a new optical instrument is purchased, it will collect high-resolution data in conjunction with the underway monitor.

The proposed work is closely related to an EVOS project mapping temperature and salinity on a ship of opportunity which transits from Valdez to Long Beach. We investigated the possibility of collaborating with this project and installing an underway nitrate monitor on the ship; however – logistic difficulties aside – the ship track would not yield a broad survey of the northern GOA, and would not permit an investigation of mechanisms that supply nutrients to the surface.

IV. SCHEDULE

A. Project Milestones

Objective 1. Map surface nutrients across the northern and central GOA
To be met by November 2003 and November 2004 (two field seasons)

Objective 2. Identify mechanisms supplying nutrients to surface waters in summer.
To be met by March 2005

Objective 3. Parameterize the relationship of nutrient distributions with physics, chlorophyll, zooplankton and fish.
To be met by February 2004 and February 2005 (two data sets)

Objective 4. Provide a mesoscale context for moorings and process studies in the eastern GOA (GLOBEC and the Steller Sea Lion Program), and for research proposed in the eastern GOA (Coastal Ocean Processes).
To be met by November 2004

Objective 5. Initiate a long-term monitoring program of nutritional status of the northern and central GOA to better understand the impact of interannual and decadal variability, and to provide nutritional forecasts to resource management teams.
To be met by November 2004

B. Measurable Project Tasks

FY 03, 1st quarter (October 1, 2002-December 31, 2002)

November 25:	Project funding approved by Trustee Council

FY 03, 2nd quarter (January 1, 2003-March 31, 2003)

January 13-17:	Attend annual EVOS Workshop (joint symposium with GLOBEC and NMFS)

FY 03, 3rd quarter (April 1, 2003-June 30, 2003)

June:	Prepare underway nitrate monitor

FY 03, 4th quarter (July 1, 2003-September 30, 2003)

Early July:	Install underway nitrate monitor
Mid-July-Mid August:	Conduct underway analysis – Survey Cruise I

FY 04, 1st quarter (October 1, 2003-December 31, 2003)

October 31:	Finish lab analyses of all frozen samples – Survey Cruise I
November 31:	Finish nutrient map – Survey Cruise I

FY 04, 2nd quarter (January 1, 2004-March 31, 2004)

February 15:	Finish parameterization of the relationship of nitrate with biophysical variables – Survey Cruise I
(dates not yet known):	Attend annual EVOS Workshop

FY 04, 3rd quarter (April 1, 2004-June 30, 2004)

June:	Prepare underway nitrate monitor

FY 04, 4th quarter (July 1, 2004-September 30, 2004)

Mid-July-Mid August:	Conduct underway survey cruise – Survey Cruise II

FY 05, 1st quarter (October 1, 2004-December 31, 2004)

October 31:	Finish lab analyses of all frozen samples – Survey Cruise II
November 31	Finish nutrient maps – Survey Cruise II

FY 05, 2nd quarter (January 1, 2005-March 31, 2005)

February 15	Finish parameterization of the relationship of nitrate with biophysical variables – Survey Cruise II
March 15	Finish analysis of the data set for identifying mechanisms of nutrient supply
(dates not yet known)	Annual EVOS Workshop

FY 05, 3rd quarter (April 1, 2005-June 30, 2005)

April 15	Submit final report (which will consist of draft manuscript for publication) to EVOS

V. RESPONSIVENESS TO KEY TRUSTEE COUNCIL STRATEGIES

A. Community Involvement and Traditional Ecological Knowledge (TEK)

In the short term, the impact of the project on communities surrounding the northern GOA will be minimal. There will some valuable interaction between local fisherman and scientists that foments mutual respect, and perhaps builds greater cooperation. In the long term, the use of fishing vessels as part of a large monitoring network would provide out-of-season employment for a number of fishermen; and, this work along with future monitoring efforts have great potential for helping resource managers secure sustainable fisheries for years to come.

B. Resource Management Applications

The vision of this program is to establish a long-term monitoring network to report on variability of the nutritional status of the GOA. Ekman transport of nutrient rich water from the central Gulf to the shelf may be a key source of nutrients for spring production; however, there appears to be significant interannual variability in nutrient concentrations, and nutrients may be declining. Linking concentrations in early spring with NPZ models of the northern GOA may help resource managers forecast production levels and juvenile fish survival for the upcoming spring, and address problems that may arise from human activities.

VI. PUBLICATIONS AND REPORTS

Short term publications (2003-2005) will include progress reports, a final report, and a publication on nutrient distributions in the eastern verses the western GOA in summer. In the long term (2005-7), we expect to synthesize GEM, GLOBEC and Steller Sea Lion research and publish several manuscripts on mechanisms of nutrient supply. In addition, we expect to publish a collaborative effort with F. Whitney on comparing nutrient depletion along Line-P with variability observed in the Northern GOA.

VII. PROFESSIONAL CONFERENCES

Project results will be presented at the annual GEM and GLOBEC workshops, and at the annual Ocean Sciences/AGU meetings. GEM results will be integrated with data from FOCI, GLOBEC, and the Steller Sea Lion program; hence, funding for travel to these meetings will be covered by these other programs. The topics of posters and/or papers presented will be related to mechanisms of on-shelf nutrient transport, entrainment of nutrients over shallow banks in summer, and the covariance of nutrient and biological distributions (chlorophyll, zooplankton, and salmon).

VIII. PERSONNEL

A. Principal Investigator (PI)

Phyllis J. Stabeno (NOAA/PMEL, 7600 Sand Point Way NE, Seattle, WA 98115, Phone: 206-526-6453, FAX: 206-526-6485, Email: stabeno@pmel.noaa.gov).

P. Stabeno will be responsible for the synthesis of GEM data with physical, chemical, and biological data collected by PMEL as part of GLOBEC, the Steller Sea Lion Program, and the CoOP program (if funded). This includes data from drifters, biophysical moorings, hydrographic sections, and satellites (color and altimetry).

2. Calvin W. Mordy (Joint Institute for the Study of the Atmosphere and Ocean, NOAA/PMEL & University of Washington, 7600 Sand Point Way NE, Seattle, WA, 98115, Phone: 206-526-6870, FAX : 206-526-6744, Email: mordy@pmel.noaa.gov.

C. Mordy will be responsible for analysis of the underway data, analysis of calibration samples, finalization of all data, the writing of progress reports and a final data report, ensuring compliance with the Trustee Council data management policy, and publication of results. Mordy will also be responsible for linking data with the Station P time series and with satellite models of sea-surface nitrate.

B. Other Key Personnel

David P. Wisegarver has spent several years working with the underway technology, and will install and oversee the underway nitrate monitor. He will prepare all reagents, prepare the on-board standard, program the instrument, and monitor operation of the analyzer during the first cruise leg (Dutch Harbor to Seward). He will also be responsible for training the science party in collection of calibration samples from the underway seawater system and in collection of samples from CTD-Niskin bottles tripped near the surface.

C. Contracts

No components of this project will be contracted out.

IX. PRINCIPAL INVESTIGATOR QUALIFICATIONS

A. Phyllis J. Stabeno

PROFESSIONAL PREPARATION

B.S. University of Washington, Mathematics, June 1972

M.A. University of California, Berkeley, Mathematics, June, 1974

Ph.D. Oregon State University, Physical Oceanography, June, 1982

APPOINTMENTS

Oceanographer, NOAA/Pacific Marine Environmental Laboratory (PMEL), 1988-present

Director: Fisheries Oceanography Coordinated Investigations at PMEL, 1998-present

Lead Physical Oceanographer: Fisheries Oceanography Coordinated Investigations, 1994-present

Research Scientist III, Joint Institute for the Study of Atmosphere and Ocean, Univ. of Wash. 1987-88.

Research Associate, Oregon State University, 1985-1986.

Research Fellow, UCG, Galway, Ireland, 1982-1984.

PUBLICATIONS

Five Relevant Publications

Stabeno, P.J., N.A. Bond, A.J. Hermann, C.W. Mordy, J.E. Overland and N. Kachel (2002): Meteorology and oceanography of the northern Gulf of Alaska. *Cont. Shelf Res.* [Accepted].

Stabeno, P.J. and A.J. Hermann (1996): An eddy-resolving model of circulation on the western Gulf of Alaska shelf. 2. Comparison of results to oceanographic observations. *J. Geophys. Res., 101*(C1), 1151-1161.

Stabeno, P.J., R.K. Reed, and J.D. Schumacher (1995): The Alaska Coastal Current: Continuity of transport and forcing. *J. Geophys. Res., 100*(C2), 2477-2485.

Stabeno, P.J., and P. van Meurs (1999). Evidence of episodic on-shelf flow in the southeastern Bering Sea. *J. Geophys. Res., 104*(C12), 29,715-29,720.

Schumacher, J.D., P.J. Stabeno, and A.T. Roach (1989): Volume transport in the Alaska Coastal Current. *Cont. Shelf Res., 9(12*), 1071-1083.

Five Significant Publications

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, and J.D. Schumacher (2001): On the temporal variability of the physical environment over the southeastern Bering Sea. *Fish. Oceanogr.10:1*, 81198.

Stabeno, P.J., J.D. Schumacher, and K. Ohtani (1999): The physical oceanography of the Bering Sea. In <u>Dynamics of the Bering Sea: A Summary of Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea,</u> T.R. Loughlin and K. Ohtani (eds.), North Pacific Marine Science Organization (PICES), University of Alaska Sea Grant, AK-SG-99-03, 1-28.

Stabeno, P.J., J.D. Schumacher, R.F. Davis, and J.M. Napp (1998): Under-ice observations of water column temperature, salinity and spring phytoplankton dynamics: Eastern Bering Sea shelf. *J. Mar. Res., 56*, 239-255.

Stabeno, P.J., J.D. Schumacher, K.M. Bailey, R.D. Brodeur, and E.D. Cokelet, (1996): Observed patches of walleye pollock eggs and larvae in Shelikof Strait, Alaska: their characteristics, formation and persistence. *Fish. Oceanogr.*, 5, 81-91.

Stabeno, P.J., and R.K. Reed (1994): Circulation in the Bering Sea basin observed by satellite-tracked drifters: 1986-1993. *J. Phys. Oceanogr., 24*(4), 848-854.

SYNERGISTIC ACTIVITIES

Professional Memberships: American Geophysical Union, Irish Meteorological Society

Fellow: Cooperative Institute for Arctic Research

Honors: PMEL Distinguished Paper Award (5 years)

Publication: Guest Editor for *Progress in Oceanography*; Bering Sea Editorial Committee for *Deep-Sea Research II*

B. Calvin W. Mordy

CURRENT POSITION

1993 Oceanographer with NOAA/PMEL and the University of Washington. Responsible for the PMEL nutrient laboratory including analysis, quality control, and publication of data generated from autoanalyzers (sea-going and laboratory), underway systems, and moored nitrate monitors.

ACADEMIC TRAINING AND SELECTED EXPERIENCE

B.S. Berry College, Chemistry, 1982

M.S. University of Kansas, Bioorganic Chemistry, 1986

Ph.D. Oregon State University, Chemical Oceanography, 1991

Postdoctoral Fellow, University of Southern California, 1991-1993

International WOCE Hydrographic Programme Planning Committee, 1995-1996

RECENT PUBLICATIONS

Mordy, C.W., P.J. Stabeno and Anne Sigleo (2002): Temporal Variability of Upwelled Nitrate off the Oregon Coast: a Moored Nitrate Time Series. *J. Geophys. Res.* [Submitted 3/02]

Stabeno, P.J., N.A. Bond, A.J. Hermann, C.W. Mordy, J.E. Overland and N. Kachel (2002): Meteorology and Oceanography of Northern Gulf of Alaska. Cont. Shelf Res. [Accepted].

Daly, K. L., W. O . Smith, Jr., G. C. Johnson, G. R. DiTullio, D. R. Jones, C. W. Mordy, R. A. Feely, D. A. Hansell, J.-Z. Zhang (2001): Hydrographic Structure and Distributions of Nutrients and Particulate and Dissolved Carbon in the Pacific Sector of the Southern Ocean. *J. Geophys. Res. (C Oceans),* **106**:7107-7124.

Zhang, J.-Z., C. W. Mordy, L. I. Gordon, A. Ross and H. E. Garcia (2000): Are Reported Trends in Deep Ocean Redfield Ratios Artifact? *Science*, **289**:1839a.

Reed, R. K. and C. W. Mordy (1999): Bering Sea Deep Circulation: Water Properties and Geopotential. *J. Mar. Res.*, **57**:763-773.

EXPERTISE AND RECENT ACTIVITIES

Since initiating the nutrient laboratory at PMEL in 1993, I have conducted nutrient analysis on 18 hydrographic cruises (including WOCE, NOAA Climate, JGOFS, FOCI, and VENTS), and have been the lead nutrient PI on 14 of those cruises. In addition, the nutrient laboratory deploys about 10 moored instruments (nitrate and iron analyzers, and water samplers) annually, and now regularly measures underway nitrate when participating on an oceanographic expedition.

In the Bering Sea and Gulf of Alaska, GLOBEC and Steller Sea Lion research focuses on deep circulation and cross-shelf transport of nutrients. A suite of eight nitrate analyzers, an iron analyzer and a plankton sampler are being moored along the Alaskan shelf at six-month intervals. In addition, repeat hydrographic lines are being sampled, and underway (surface) nitrate is being collected on hydrographic cruises. Initial results show that salty, nutrient rich water intrudes up the shelf during seasonal relaxation of upwelling winds, and that bathymetric steering (up-canyon flow) of deep shelf water appears to be an important mechanism of cross-shelf transport of nutrients. In addition, surface waters in the western GOA in summer have high surface chlorophyll-a concentrations (as observed by satellite) suggesting relatively high concentrations of nutrients (including iron) in the surface mixed layer. To better understand these blooms, we intend to investigate mechanisms of nutrient transport – especially nutrient pumping over shallow banks.

Participation with the GLobal Ocean Data Analysis Project (GLODAP) nutrient group centers on re-evaluating Redfield ratios using the high quality World Ocean Circulation Experiment (WOCE) nutrient data set. Suggested corrections to the Pacific WOCE data are completed, and work has begun on evaluating Redfield ratios in the Indian and Pacific Oceans.

Future work includes repeat hydrographic sections along World Ocean Circulation Experiment (WOCE) cruise lines, and a proposal was submitted to the Coastal Ocean Processes (CoOP) Program to examine buoyancy driven transport in the eastern GOA.

X. LITERATURE CITED

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Dugdale, R.C., C.O. Davis and F.P. Wilkerson (1997) Assessment of new production at the upwelling center at Point Conception, California, using nitrate estimated from remotely sensed sea surface temperature. *J. Geophys. Res*. **102**:8573-8585.

Dugdale, R.C., A. Morel, A. Bricaud and F.P. Wilkerson (1989) Modeling new production in upwelling centers: A case study of modeling new production from remotely sensed temperature and color. *J. Geophys. Res*. **94**:18119-18132.

Favorite, F., A.J. Dodimead, and K. Nasu (1976) *Oceanography of the subarctic Pacific Region, 1960-1971*. International North Pacific Fisheries Commission Bulletin No. 33, 187 pp.

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Mantua, N.J., S.R. Hare, Y. Zhang, J.M, Wallace and R.C. Francis (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Am. Met. Soc*. **78**:1069-1079.

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Reed, R.K. and J.D. Schumacher (1986) Physical Oceanography. In: *The Gulf of Alaska: Physical Environment and Biological Resources*, D.W. Hood and S.T. Zimmerman, eds. Ocean Assessment Division, NOAA, 57-75.
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Welch, D.W., B.R. Ward, B.D. Smith and J.P Eveson (2000) Temporal and spatial responses of British Columbia steelhead (*Oncorhynchus mykiss*) populations to ocean climate shifts. *Fish Oceanogr.* **9**:17-32.
Whitney, F.A., C.S. Wong and P.W. Boyd (1998) Interannual variability in nitrate supply to surface waters of the Northeast Pacific Ocean. *Mar. Ecol. Prog. Ser.* **170**:15-23.

Whitney, F.A., D.L. Mackas, D. Welch and M. Robert (1999) Impact of the 1990s El Niños on nutrient supply and productivity of Gulf of Alaska waters. *In* Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/98 El Niño Event on the North Pacific Ocean and its Marginal Seas. Pices Scientific Report No. 10, pp. 59-62.

XI. SUPPLEMENTAL DOCUMENT

Letter of collaboration from E.D. Cokelet

EXXON VALDEZ OILSPILL TRUSTEE COUNCIL
PROJECT BUDGET

Budget Category:	Proposed FY 03						
Personnel	$30.9						
Travel	$2.5						
Contractual	$0.0						
Commodities	$1.0						
Equipment	$0.0						
Subtotal	$34.4						
General Administration	$3.1						
Project Total	$37.5						
Other Funds	$186.4						

Comments:
Cost Sharing
Stabeno - 1 month salary, $21.8k
Shiptime - 27 days @ $5k/day, $135k
Nitrate Monitor - $22k
Annual EVOS Workshop - 2.6k
Calibration Sample Analysis - $5k

Total $186.4k

FY 03

Received 9/3/02

Project Number: G-030654 (TC approved 11/25/02)
Project Title: Surface nutrients over the Shelf and Basin
Agency: NOAA

FORM 3A
TRUSTEE
AGENCY
SUMMARY

EXXON VALDEZ OILSPILL TRUSTEE COUNCIL
PROJECT BUDGET

Personnel Costs:		GS/Range/	Months	Monthly		Personnel
Name	Description	Step	Budgeted	Costs	Overtime	Sum
P. Stabeno	NOAA Oceanographer	15	1.0	N.C.		0.0
C. Mordy	JISAO/Oceanographer		2.0	5.7		11.4
D. Wisegarver	NOAA/Research Chemist	12/10	1.0	14.7	4.8	19.5
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
	Subtotal		4.0	20.4	4.8	
					Personnel Total	$30.9

Travel Costs:	Ticket	Round	Total	Daily	Travel
Description	Price	Trips	Days	Per Diem	Sum
					0.0
D. Wisegarver, Participation on 1st leg of Research Cruise					0.0
Airfare is one-way Seattle to Dutch Harbor, returning Kodiak to Seattle	1.8	1	16		1.8
Dutch Harbor per diem			2	0.2	0.4
Seward per diem			1	0.3	0.3
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
				Travel Total	$2.5

FY 03

Project Number: G-030654 (FY 03)
Project Title: Surface nutrients over the Shelf and Basin
Agency: NOAA

FORM 3B
Personnel
& Travel
DETAIL

***EXXON VALDEZ* OILSPILL TRUSTEE COUNCIL**
PROJECT BUDGET

Contractual Costs:	Contract
Description	Sum
When a non-Trustee organization is used, the 4A and 4B forms are required. **Contractual Total**	$0.0

Commodities Costs:	Commodity
Description	Sum
Parts & Supplies for the Underway Nitrate Monitor (Reagent Bags, Tubing, Fittings, Chemicals, Standards)	0.5
Parts & Supplies for the AutoAnalzer (Tubing, Fittings, Chemicals, Standards)	0.5
Commodities Total	$1.0

FY 03

Project Number: G-030654 (FY 03)
Project Title: Surface nutrients over the Shelf and Basin
Agency: NOAA

FORM 3B
Contractual &
Commodities
DETAIL

EXXON VALDEZ OILSPILL TRUSTEE COUNCIL
PROJECT BUDGET

New Equipment Purchases: Description		Number of Units	Unit Price	Equipment Sum
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
				0.0
Indicate replacement equipment purchases with an R.			**New Equipment Total**	$0.0

Existing Equipment Usage: Description	Number of Units	Inventory Agency
Laboratory AutoAnalyzer	1	NOAA
Underway Nitrate Monitor	1	NOAA
Underway Flowthrough System	1	NOAA

FY-03

Project Number: G-030654 (FY 03)
Project Title: Surface nutrients over the Shelf and Basin
Agency: NOAA

FORM 3B
Equipment
DETAIL